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The climatology of field haydrying II: Application of a bulk model of haydrying in two contrasting climates

by N Thompson

1. Introduction A model which lends itself to the classification of climate in relation to its potential for the field-drying of hay was described by Thompson (1981a). A slightly modified version of this model has now been programmed to run with climatological data from the Agromet data set. The present memorandum outlines the programmed system, and describes results obtained using one season's meteorological data from two contrasting sites in the United Kingdom.

2. Outline of the model application Most of the details of the model were described in the earlier paper and will not be repeated here: present comments on the model will be largely confined to descriptions of significant developments incorporated in the current version of the model. However it is useful to indicate first the overall scheme in which the model is employed, and the major assumptions in its use.

Any method of assessing the climatology of haydrying by simulation requires a number of assumptions regarding the practice of haymaking throughout the season. Factors of importance here include the age of grass when cut (i.e. whether a first cut or regrowth), the date of cut, and the type of conditioning. Crops which are never short of water, and are well-fertilised, will generally be heavier, leafier and with higher water contents than swaths which are managed less intensively. Crops cut with a conditioner/ mower and spread to form a swath which is well set up will dry quicker than unconditioned, unspread swaths. On the other hand leaching losses from strongly-conditioned swaths are larger than from unconditioned swaths exposed to the same rainfall. To make progress it is necessary to assume a simple basic framework for the practice of haymaking within which the model is run: by changing some of the model parameters it is possible to explore a few of the factors just mentioned, but to treat them all is beyond the scope of an investigation of general haydrying climatology.

An outline of the scheme which is used is as follows:

(i) Beginning on 1 March, when the soil is assumed to be at field capacity, a MORECS-based model of water use by grass is employed to calculate the soil moisture each day in reservoirs relevant to (a) soil evaporation and (b) transpiration: these calculations conclude in the latter half of September.

(ii) It is assumed that a cut for hay can be taken on any day from 1 May to 20 September, with soil moisture at the time of cut obtained from the results of §(i): the swath usually contains 5t of dry matter per hectare.

(iii) Time of cut is 0900Z: the crop is spread uniformly over the stubble after cutting, and turned occasionally to minimise the effects of vertical variations in the swath.

(iv) Rainfall (in 12 hour totals from 0900-2100Z, and 2100-0900Z) is assumed to fall continuously and uniformly, from the start of each period, with durations in each period obtained from the daily duration on the assumption of proportionality to the corresponding rainfall amounts.

(v) Water content of the grass at cutting is 400%: any surface moisture at the time of cut is ignored.

(vi) Water loss from the swath tissue is via stomata until water content falls to 300%, and is thereafter via cuticle, cuts or abrasions: after stomatal closure the resistance to water transfer to or from the swath tissue ("tightly-bound" moisture) is inversely proportional to tissue moisture content.

(vii) Rainfall is intercepted by swath, stubble and soil: condensation is intercepted by the swath alone.

(viii) Swath moisture can be either tightly-bound (tissue moisture, $\leq$ 400%), loosely-bound (loosely + tightly-bound moisture $\leq$ 900%) and free-surface (up to 150%.)

(ix) The evaporative flux from the swath-covered surface includes water evaporated directly from the soil, from the stubble (transpiration or intercepted water) and from the swath: however, when the swath contains free water, this is evaporated before losses can occur from the loosely or tightly-bound swath moisture or from the soil.

(x) Tissue moisture increases while the swath contains loosely-bound moisture, or when the ambient relative humidity exceeds the equilibrium relative humidity: loosely-bound moisture is evaporated before losses of the tightly-bound tissue moisture can occur.

(xi) Total water loss from the swath-covered surface is calculated using the modified form of the Penman-Monteith equation given by Thompson (1981a): this loss is apportioned between swath, stubble and soil according to leaf areas of swath and stubble, appropriate resistances and the vapour- pressure deficits (standard and equilibrium deficits).

(xii) After loss of free moisture from the swath, the tissue moisture content (and loosely-bound moisture content, if present) is calculated at 2 hourly intervals in three main periods each day (0900-sunset, sunset-dawn, dawn-0900Z).

(xiii) Calculations for each cut end when tissue moisture content falls to 25%, or after 240 hours, whichever is the earlier.

The earlier paper noted that one difficulty in the application of the model was in the treatment of the evaporation of loosely-bound moisture from the swath. It was suggested then that a relation of the form

$$r_s = b\,(900-W_{L+T})/W_{L+T} \qquad (1)$$

might be applied, where

r_s = swath resistance per unit swath surface area (s/m)

W_{L+T} = percentage total of loosely and tightly-bound moisture

900 = maximum percentage moisture content of swath

b = constant

:however, the magnitude of the constant b could not be specified at the time. A field haydrying experiment reported by Rumney (1982) now provides data from which an approximate value of b can be estimated: this value is around 300 s/m.

Results and discussion The model was run with meteorological data from Honington and Aberporth in 1978. Two values of swath resistance (per unit swath surface area) were used to calculate transfer of tightly-bound moisture W_T : they were $r_s = 2 \times 10^6/W_T$ and $1 \times 10^6/W_T$ (s/m). They are based on experimental data described by Sparks (1980), on experimental results of Rumney (1982) and on comparisons of a bulk model of haydrying with experimental results (Thompson 1981b). The larger value may be taken as appropriate to the drying of an unconditioned swath subjected to gentle treatment at mowing, while the lower value would be more appropriate to a swath conditioned at cutting to improve its drying rate.

A summary of the results for the higher value of swath resistance is given in Figure 1. The range of final moisture contents which has been plotted (25-40%, dry weight basis) is typical of that within which hay is baled in a field-drying system (Raymond et al 1978). At the lower limit the hay would be ready usually for immediate storage. At the upper limit some further field conditioning (in the bale) might be required before safe storage is possible. A feature of the results at both sites is the good drying period (3 or 4 weeks long) for cuts taken after the first week or so in May. After then, however, the problems of making hay reliably in the damper climate of West Wales are clearly revealed, with no cuts drying to 25% moisture within 10 days during the remainder of the season, and only a small number reaching 40%: in contrast, there were spells at Honington throughout the season in which it was possible to make hay, even despite several rather wet periods.

Table 1 presents the results in rather more detail by showing the length of periods required to reach certain swath moisture contents, and the amounts of rain falling. The shortest periods in which hay dried to 25% moisture content were a little in excess of 72 hours, and these occurred at the end of May. In a less unsettled summer with spells of fine warmer weather from June onwards it would be expected that the model would predict drying to 25% in somewhat shorter periods, say 48 to 72 hours. These durations of periods, and the values actually calculated by the model from the Aberporth and Honington data are consistent with experience, and provide general support for the usefulness of the model. The often less than favourable conditions for drying in this particular year are demonstrated by the small number of cuts (41 out of 143) which reached even 40% moisture in less than 6 days at Honington. The picture was even worse at Aberporth where only 15 cuts achieved that moisture level within 6-day periods.

Rainfall on the swaths reaching 25% moisture content within 6 days was negligible: however, rainfall on swaths taking between 6 and 10 days to reach this moisture level was sometimes substantial enough (5-10mm) to cause significant leaching losses. The rainfall on swaths which failed to dry to 40% in 10 days was often large, leading to substantial leaching: the often-prolonged periods of dampness of these swaths would also cause the development of microrganisms which can produce further losses of dry matter as well as reducing palatability.

Any prolongation of the period required to make hay will increase losses of dry matter and quality, through factors including for example increased re-wetting by dew and break up of the swath material during turning, as well as leaching and respiration. "Good" hay will not be made therefore unless the drying period is restricted in length. An ideal maximum drying period would be not larger than say 72 hours, but this might be extended to around 120 hours in fine weather without substantial dewfall. On these bases the model results which have just been described showed that the haymaking season in 1978 provided few opportunities to make good hay. However, a swath which has been conditioned to reduce its resistance to drying will sometimes lead to good haymaking periods in a season which would be unsatisfactory for slower-drying swaths. Figure 2 and Table 2 show the results obtained when the swath resistance is halved to simulate the drying of conditioned swaths. Comparison with Figure 1 demonstrates that the lower resistance value enhances considerably the haydrying prospects for Aberporth in particular: for example the disparity in number of swaths reaching the upper and lower limits of the swath drying range (25-40%)

within 10 days is less marked than before. In the context of making good hay (within less than 5 days), the reduction of swath resistance now allows 37% of the Honington cuts, and 17% of those at Aberporth to reach 25% moisture content in the period (Table 2), compared to less than 10% before: corresponding figures for swaths reaching 40% moisture now increase to 62% and 33% at Honington and Aberporth respectively, a startling improvement on the previous figures of 17% and 7%. Clearly, the advantages of decreasing the swath resistance are considerable. Equally though, the sensitivity of the calculated numbers of haydrying occasions to the exact value of the swath resistance makes an objective assessment of haydrying climatology more difficult, and suggests that a full scale assessment of haymaking climate, using the model with climate data for many years from a number of sites, should include some calculations for a range of swath resistances.

Conclusions The bulk model of haydrying has been used to compare the haydrying climates of two contrasting sites in a single year. The results demonstrate the difficulties in making good hay in an unsettled season, particularly near the West coast, and show the considerable advantage to be gained by conditioning the swath. The strong dependence of haydrying opportunities on swath resistance suggests that the model should be used with a range of swath resistances when making a full assessment of haymaking climatology.

Any comments or suggestions on this paper should be sent to the author.

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Table 1 Number of cuts drying to stated moisture contents within 10 days of cutting ($r_s = 2 \times 10^6 / W_T$)

Moisture content reached (%)	Number of days	Period in which cuts were taken (1 ≡ 1st May)											
		1-20		21-40		41-60		61-80		81-100		101-120		121-143	
		Ab.	Hon.	Ab.	Hon.	Ab.	Hon.	Ab.	Hon.	Ab.	Hon.	Ab.	Hon.	Ab.	Hon.
25	3*														
	4**			4	5										
	5			4	5								2		
	6			2	1								1		
	7	1			3				1		2		3		
	8	4	1		2		1		5		2		3		
	9	3	2				1		4				2		1
	10	1	1				1		4						2
Totals		9	4	10	16		3		14		4		11		3
30	3				1										
	4			4	7										
	5			4	2								2		
	6			2	3						2		4		
	7	5			4		1		7		2		2		
	8	2	2		1		1	1	4		1		2		2
	9	1	1				1		3				2		1
	10	1	2	2	1	2	1	2	2		1	1			6
Totals		9	5	12	19	2	4	3	16		6	1	12		9
40	3			4	4										
	4			4	6								2		
	5			2	4		1		1		3		3		
	6	4		1	5		2		5		2		3		
	7	3	1	1	1		1	1	3		1		3		3
	8	1	3	2		2	2	3	5				2		7
	9	1	2	2		2	1	1	1		1	1	1		7
	10	3	1	4		1		1	1		2	3			1
Totals		12	7	20	20	5	7	6	16		9	4	14		18
Lowest moisture contents reached by remaining cuts	40-50	1(6)+	2(11)			2(8)	1(32)	1(10)	2(17)		4(30)	10(15)	4(4)		3(14)
	50-70	1(6)	5(18)			3(16)	2(34)	6(16)		8(32)	1(84)	6(29)	2(7)	17(11)	2(11)
	70-100	6(8)	6(21)			4(8)	2(40)	3(25)	2(24)	7(32)	5(52)			6(21)	
	> 100					6(22)	8(38)	4(38)		5(27)	1(59)				

*48-72 hours after cutting **72-96 hours after cutting etc

+Figures in brackets are rainfall totals on swath in 10 days after cutting

Table 2 Number of cuts drying to stated moisture contents within 10 days of cutting ($r_s = 1 \times 10^6 / W_T$)

Moisture content reached (%)	Number of days	Period in which cuts were taken (1 ≡ 1st May)													
		1-20		21-40		41-60		61-80		81-100		101-120		121-143	
		Ab.	Hon.	Ab.	Hon.	Ab.	Hon.	Ab.	Hon.	Ab.	Hon.	Ab.	Hon.	Ab.	Hon.
25	2			3	4										
	3			6	8		2		1		2		4		
	4	3		2	5	2	1	1	4		3		3		2
	5	4	1	2	2	1	2	1	4		2		2		2
	6	1	4	1	1	2	2	3	3		1	1	3	1	7
	7	1	2	2		2	1	2	3	1	1	3	2	1	6
	8	2	1	2		1	1		1		2	5	1		1
	9	2	1	1				1	1	1	2	4	1	1	1
	10	1	1	1				2	1	1	2	3	1	1	1
Totals		13	10	20	20	8	9	10	18	3	15	16	17	4	20
30	2			5	5										
	3			4	7		2		1		3		4		
	4	6		2	5	4	1	2	6		3		4		3
	5	1	2	2	2	2	4	2	4		2		3	1	6
	6	1	4	3	1	1	1	2	3		1	1	4	2	6
	7	1	1	1		1	1	2	1	1	2	5	1	1	4
	8	2	1	2				1	1	1	2	5	1	2	2
	9	1	3	1		2		1	1	1	1	3	2	3	1
	10	1	3					1	1	2	1	2	1		1
Totals		13	13	20	20	10	9	11	18	5	15	16	20	9	23
40	2			7	9		2						2		
	3	3		5	6	2	1		3		5		4		2
	4	4	1	4	4	2	3	4	7		3	2	6	1	6
	5	1	6	1	1	2	1	3	3		2	4	5	2	6
	6	2	2	2		3	2	2	2	1	1	4		4	4
	7	2	3	1		2		1	1	3	1	5	1	4	4
	8	3	4			2			1	2	1	3	1	3	1
	9	2	2					3	1	3	1	2	1	2	
	10	2	2					1	1	3	1			4	
Totals		19	20	20	20	13	9	14	19	12	15	20	20	20	23
Lowest moisture contents reached by remaining cuts	40-50	1(7)				1(11)	1(34)	2(24)	1(26)	3(42)	3(57)	3(42)		3(22)	
	50-70					3(25)	5(38)			4(24)	2(73)	4(34)			
	70-100					3(22)	5(39)	4(37)		1(31)		1(31)			
	> 100														

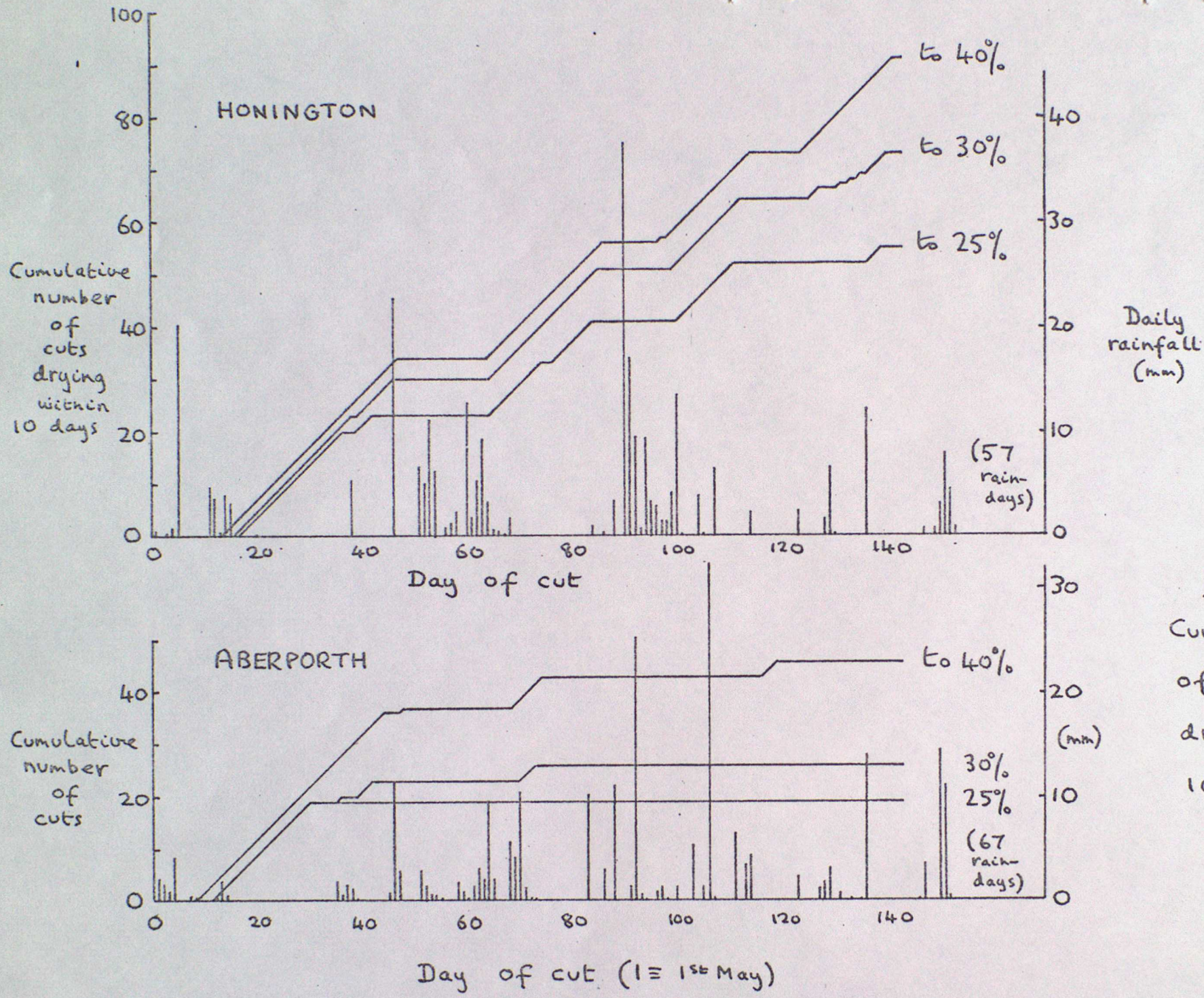
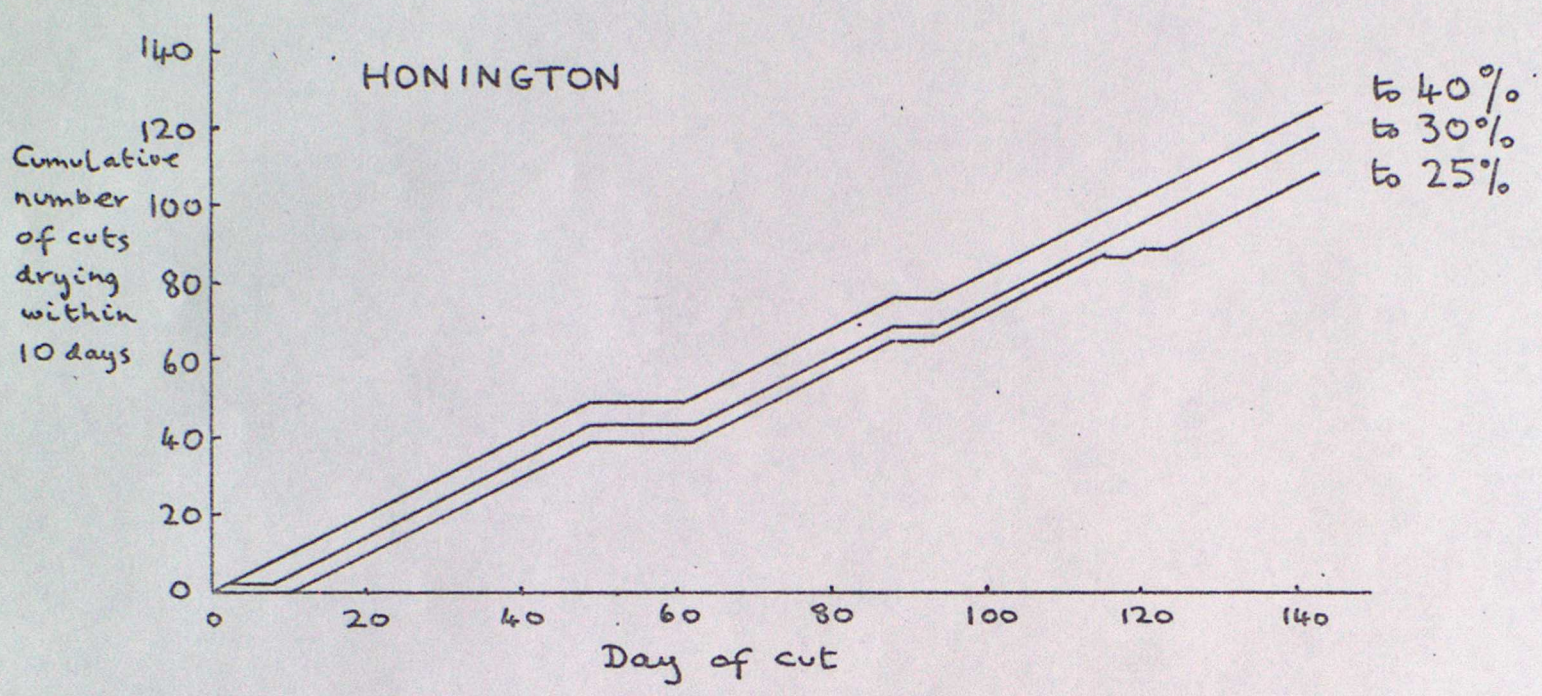


Figure 1

Cumulative number of cuts which dried within 10 days in 1978



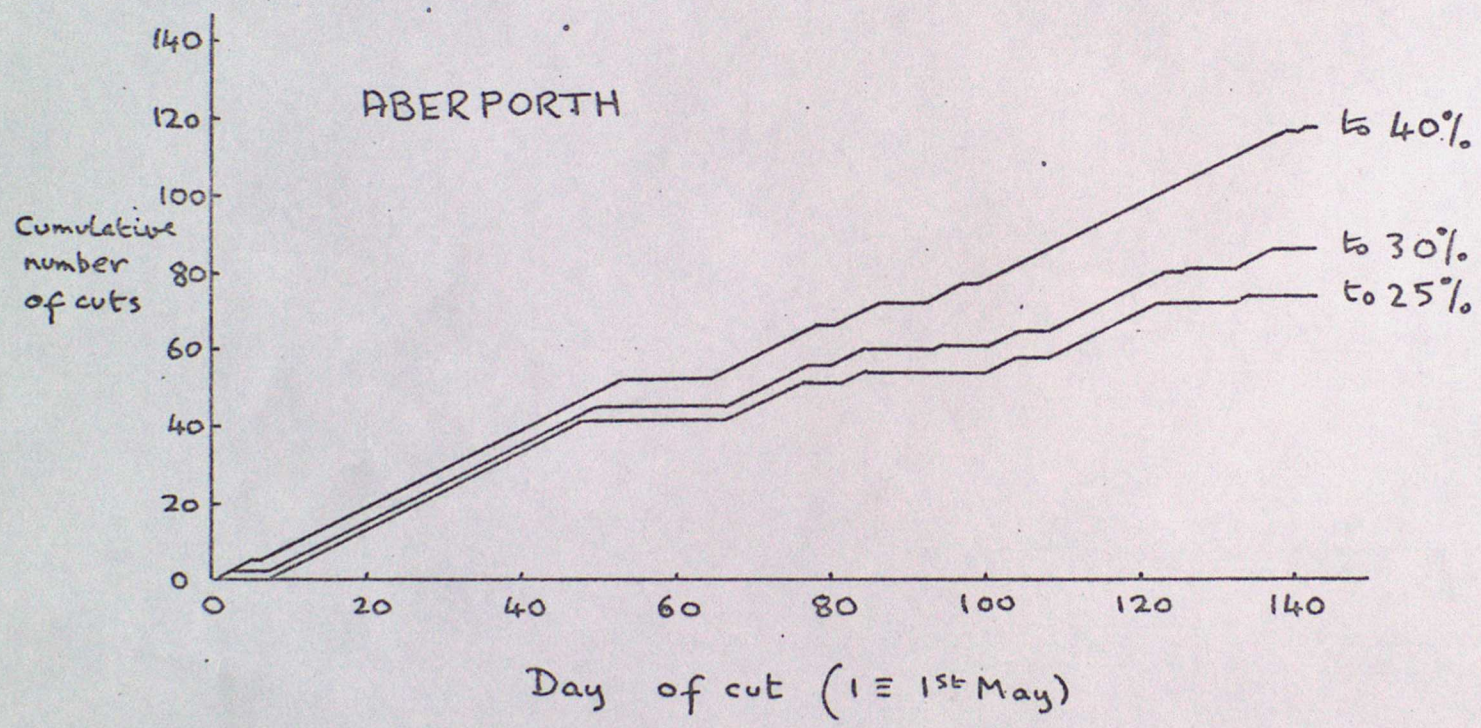


Figure 2

Cumulative number of cuts drying within 10 days when swath resistance is halved